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Determination of Optimal FDM Parameters Settings for PC/ABS Blend using Taguchi Method

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Abstract: This paper shows an experimental investigation on dimensional behaviour of Polycarbonate/ Acrylonitrile Butadiene Styrene (PC/ABS) blend material parts fabricated on Fused Deposition Modeling (FDM) machine. For that total 27 parts were manufactured to study effects of FDM parameters on top surface flatness error, surface roughness and part build time quality characteristics of parts. Reduction in build time and material consumption without compromising its dimensional accuracy are the major objectives of many industries, so in this work part printed without support structures. A Taguchi's Design of experiment was used to study effect of five parameters at three levels such as layer thickness, raster width, extrusion temperature, bed temperature and printing speed on quality characteristics. Analysis of variance (ANOVA) method also used to find out significant parameters and confirmation test of experimental result were also performed to verify the optimal settings of parameters. Results of this work showed different combination of FDM process parameters for optimum quality characteristics.

Keywords: FDM, PC/ABS blend material, Taguchi's method, surface roughness, flatness, build time.

I. INTRODUCTION

The profit of production is depends upon manufacturing of quality product with less cost and time and this makes company competitive in market. So intent of all manufacturers to rapidly manufacture and deliver the customized product within a time. For these types of application Rapid Prototyping (RP) processes are suitable. RP is a type of Additive Manufacturing (AM) process, in that parts are fabricated by addition of materials in layered format. These processes were developed in the early of 1986's for production of prototypes [1]. These processes are also called as Three Dimensional (3D) printing process, because it create any physical 3D models or object of any oddly shaped in RP machines by using Computer Aided Design (CAD) data. These processes have main four types classified according to their manufacturing process and use of raw material. At the time of introduction of 3D printing machine there was some limitation such as parts were not accurate, cost of machines were high and limited to print materials mostly uses only thermoplastic materials but now days due to advancement in printers they can print metal material also using x-rays and cost of machines also reduced. Stereolithography (SLA), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM) and Fused Deposition Modeling (FDM) are the main types of 3D printing processes [1, 2]. In that FDM is mostly used 3D printing machine because price of machine and materials is less than other technique but limitation to print high strength materials, manufacturing of part with dimensional accuracy and surface finish etc. and this was developed in 1990's by Stratasys Inc. [3]. So, focus of present study is to obtain optimal combinations of Fused Deposition Modeling (FDM) machine process parameters to improve surface finish and dimensional accuracy of parts.

II. LITERATURE SURVEY

Several research have been performed to find out impact of different FDM process parameters to optimize a part quality characteristics such as tensile strength, flexural strength, creep strength, impact strength, dimensional accuracy, surface finish, build time material consumption, but the progress is slow because there is very difficult to set parameters. O. A. Mohamed et al [3] performed research to increase dynamic flexural strength of PC-ABS blend material part by controlling six parameters these are layer thickness, air gap, raster angle, build orientation, road width and number of contours. This experimentation was completed using Q-optimal response surface methodology and ANOVA method. Result of this experimentation showed dynamic flexural strength of part was improved by an increasing the number of contours with zero air gaps and decrease in layer thickness. K. Thrimurthulu et al [4] performed experimentation to find out the best part deposition orientation which give minimum surface roughness and reduce the build time of FDM printed parts for ABS material. In this experimentation researcher had used Real coded genetic optimization method. In that best results were obtained when part orientation decreased. O. S. Carneiro et al [5] compared compression molded part with FDM part with polypropylene (PP) and Glass Reinforced Polypropylene (GRPP) material. Results of this work showed, raster orientation $\pm 45^\circ$, lower layer thickness (0.20mm) and increase in infill (100%) was most important to

maximize tensile strength. Also it concluded that FDM parts can compete with conventional manufacturing processes with mechanical properties. O. A. Mohamed et al [6] performed optimization for PC-ABS blend material to increase creep strength of parts fabricated in FDM. In this work result showed creep displacement decreased when part printed with slice height at 0.2540 mm, air gap at 0mm, raster fill angle at 0° , bead width at 0.4572mm, part print direction at 20° and number of shells at 8. M. Halonen [7] this work is in injection molding process to study effect of different combination of PC/ABS on blend on mechanical properties and thermal properties of parts with variation of rubber content in ABS. Result showed different combination gives different mechanical properties like 70/30 (PC/ABS) gives high strength to the parts and increase in % of rubber content in ABS gives high impact strength. From that it is concluded that increase in percentage of PC in ABS improves mechanical properties but it effects on process ability in manufacturing of parts. Ishtiaq Ahmed et al [8] showed different FDM problems in part printing and how to solve them by adjustment of parameters settings. O. A. Mohamed et al [9] concluded storage and loss modulus of PC/ABS blend material increases as increase in layer thickness and number of contours and by decreasing in air gap, raster angle and orientation of part. Also, mechanical damping capacity of parts was increased by increasing layer thickness, road width value and decrease in part orientation. K.G. Jaya Christiyani et al [10] worked on optimization of FDM process parameters to increases tensile strength and flexural strength of ABS+hydrous magnesium silicate parts. Best result was obtained at lower layer thickness (0.2mm) and lower printing speed (30mm/s) to increase tensile and flexural strength of parts. O. A. Mohamed et al [11] showed optimum combination of FDM process parameter to increase dynamic mechanical performance of PC/ABS blend material parts using I-optimal response surface methodology. The optimum combination of parameters was layer thickness at 0.3302 mm, air gap at 0 mm, raster angle at 14.6249° , build orientation at 5.568° , road width at 0.470 mm and number of contours at 10 to increase properties. O. Luzanin et al [12] performed experimentation on Polylactic Acid (PLA) material to improve surface finish by controlling extrusion temperature and extrusion speed at three levels. At last result showed higher extrusion temperature (235°C) and lower printing speed (40mm/s) helps to increase surface finish of the parts. From above literature survey it is found that there is less work on PC/ABS blend material to study effect of layer thickness, raster width, extrusion temperature, bed temperature and printing speed combination on dimensional accuracy and on mechanical properties of the parts.

III. EXPERIMENTAL DETAILS

In the present work DOE was done using Taguchi optimization method in MINITAB 17 software and L27 OA were selected for this work shown in table 1. These selections of array was based on five parameters at three levels such as layer thickness (A) in mm, raster width (B) in mm, extrusion temperature (C) in $^\circ\text{C}$, bed temperature (D) in $^\circ\text{C}$ and printing speed (E) in mm/sec. For that, in this study major quality characteristics examined were surface roughness (Ra) in μm , build time in sec. (BT) and flatness (F) error in mm for PC/ABS blend material. In that first, workpiece was designed in CATIA V5 CAD modeling software shown in figure. 1 and then converted into .stl (Standard Triangulation Language) file. Then Ultimkaer Cura 3.4.1 software was used to generate the tool path parameters for all the parts. First, total 8 samples were manufactured for pilot experimentation to select ranges of parameters on FDM printer, shown in figure 2 (LulzBot Taz 6) [13]. Next levels of parameters were selected according pilot reading and ranges of machine parameters settings. During manufacturing of parts build time status was recorded on computer screen. Then Surface roughness was measured (Top and side faces) on surface roughness tester (Mitutoyo, SJ210) and flatness error (Top surface) of the part measured by using CMM.

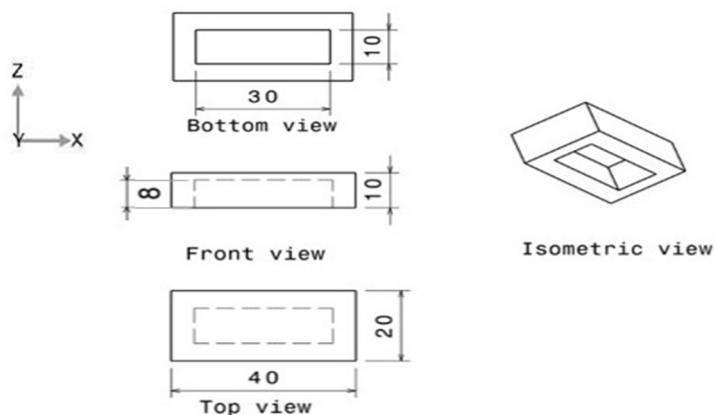


Fig. 1 Sketch of workpiece

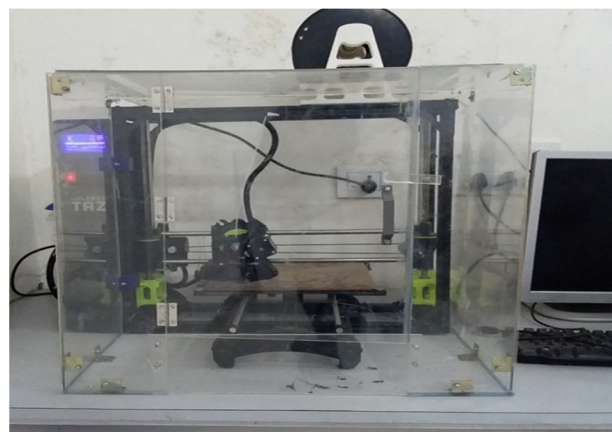


Fig. 2 Photograph of LulzBot TAZ 6 printer

IV. EXPERIMENTAL RESULTS

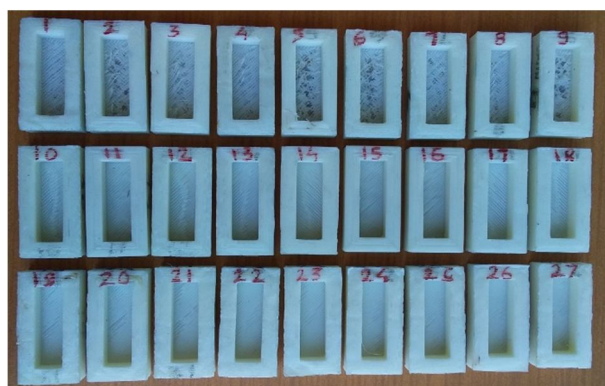
Following Table. 1 shows experimental results of twenty seven experiments using Taguchi's method for surface roughness, build time and flatness error of the FDM parts and figure 3 shows photograph of L27 experimental fabricated parts.

TABLE I Experimental result by using Taguchi's method

Exp. No.	Input parameters					Performance parameters		
	A (mm)	B (mm)	C (°C)	D (°C)	E (mm/s)	BT (min)	Ra (μm)	F (mm)
1	0.1	0.45	260	100	20	138	5.3994	0.2125
2	0.1	0.45	270	105	30	95	5.649	0.2045
3	0.1	0.45	280	110	40	73	6.2598	0.2099
4	0.1	0.50	260	105	30	89	6.5136	0.2392
5	0.1	0.50	270	110	40	69	6.8864	0.2199
6	0.1	0.50	280	100	20	129	6.1621	0.2502
7	0.1	0.55	260	110	40	63	7.682	0.1758
8	0.1	0.55	270	100	20	120	6.5906	0.1799
9	0.1	0.55	280	105	30	82	6.8048	0.1763
10	0.2	0.55	260	100	30	43	9.376	0.1163
11	0.2	0.55	270	105	40	33	11.0435	0.1052
12	0.2	0.55	280	110	20	63	10.1846	0.1392
13	0.2	0.45	260	105	40	38	11.849	0.1765
14	0.2	0.45	270	110	20	72	8.4307	0.1943
15	0.2	0.45	280	100	30	49	8.6454	0.2001
16	0.2	0.50	260	110	20	68	8.6943	0.2130
17	0.2	0.50	270	100	30	46	9.156	0.1440
18	0.2	0.50	280	105	40	36	10.5865	0.1263
19	0.3	0.50	260	100	40	25	14.4853	0.2702
20	0.3	0.50	270	105	20	47	12.7354	0.3380
21	0.3	0.50	280	110	30	32	13.6375	0.3203
22	0.3	0.55	260	105	20	44	14.1014	0.2740
23	0.3	0.55	270	110	30	30	14.2952	0.2662
24	0.3	0.55	280	100	40	23	14.6061	0.2531
25	0.3	0.45	260	110	30	35	13.8359	0.3512
26	0.3	0.45	270	100	40	27	13.9623	0.2756
27	0.3	0.45	280	105	20	51	12.6465	0.3711



A. Top view of FDM parts



B. Bottom view of FDM parts

Fig. 3 Photograph of L27 experimentation workpieces of PC/ABS blend

A. ANOVA for Surface Roughness (R_a)

Effect of FDM process parameters on surface roughness for lower the better performance characteristics at different levels is shown in following figure 4. And table 2 shows ranks of parameters by using S/N ratio calculation.

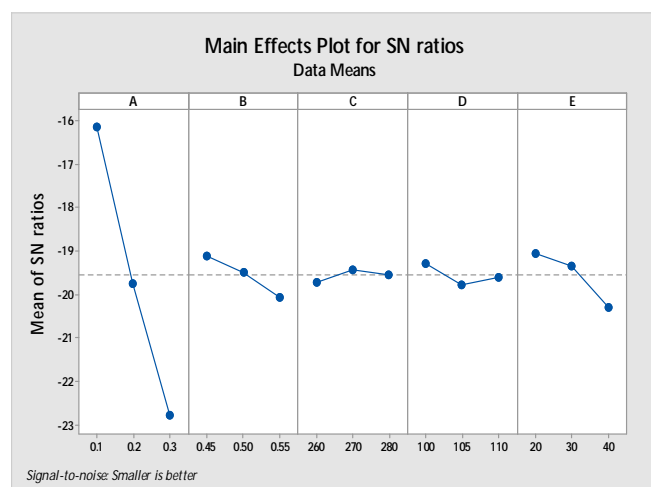


TABLE II Response table for S/N ratio of Surface roughness (μm)

Level	A	B	C	D	E
1	-16.13	-19.12	-19.71	-19.29	-19.05
2	-19.74	-19.48	-19.43	-19.77	-19.33
3	-22.79	-20.07	-19.53	-19.61	-20.29
Delta	6.66	0.94	0.27	0.48	1.25
rank	1	3	5	4	2

Fig. 4 Main effect plot for S/N ratio of surface roughness (μm)

Above figure. 4 shows, lower values of layer thickness (0.1mm), raster width (0.45mm), bed temperature (100°C) and printing speed (20mm/s) and medium level of extrusion temperature (270°C) was the optimum combination to reduce surface roughness of PC/ABS blend material parts. Also variation of surface roughness values was shown in above Table 1. This Table 1. shows lower roughness value was observed for experiment no. 1 with 5.3994 μm and higher 14.6061 μm for experiment no. 24.

TABLE III Analysis of variance (ANOVA) for surface roughness

Source	DOF	Adj SS	Adj MS	F- Value	P- Value	% Contribution
A	2	245.372	122.686	412.55	0.000	92.73 %
B	2	3.808	1.904	6.40	0.009	1.44 %
C	2	0.613	0.307	1.03	0.379	0.23 %
D	2	0.703	0.352	1.18	0.332	0.27 %
E	2	9.342	0.352	15.71	0.000	3.53 %
Error	16	4.758	4.671			
Total	26	264.595	0.297			

The significance of FDM parameters for surface roughness values was shown in Table 3. using ANOVA. This analysis was carried out with 0.05 significance level (95% of confidence level) and this shows layer thickness, printing speed and raster width were the most significant parameters of FDM for surface roughness. Also, this ANOVA table shows that, layer thickness has more percentage of contribution with 92.73% to reduce surface roughness. Because higher value of layer thickness produces stairsteps effects on side faces by increasing peaks and valley distance and this increase roughness of parts with higher printing speed and raster width. However, extrusion temperature and bed temperature shows less significant for surface roughness in this work.

B. ANOVA for Build time (BT)

Effect of process parameters on build time for lower the better performance characteristics at different levels is shown in following figure 5. And Table 4 shows important parameters with the help of ranks for build time by using S/N ratio calculation.

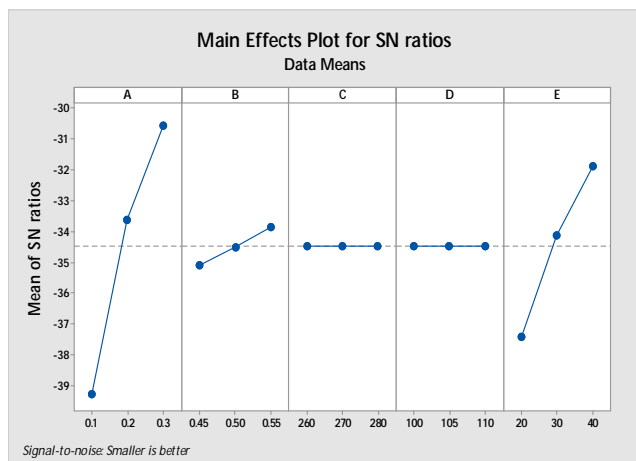


Fig. 5 Main effect plot for S/N ratio of Build time (BT)

Above figure 5. and table 4 shows layer thickness, printing speed, bed temperature and raster width were the most significant parameters to reduce build time. In that part build time was more significantly influenced by changing the layer thickness from 0.1mm to 0.3mm, raster width from 0.45mm to 0.55mm and printing speed from 20mm/s to 40mm/s but this affected on to increase surface roughness values shown in above table 1. Table 1. shows lower build time was observed for experiment no. 24 with 23min and higher part build time 138 min for experiment no. 1. ANOVA for build time was shown in following table 5 with 0.05 significance value. This shows layer thickness and printing speed has a more percentage of contribution with 67.70%, 26.04% respectively of FDM parameters to reduce build time of parts. From figure 5 and table 4 optimum combination obtained for minimum build time at higher values of layer thickness at 0.3mm, raster width at 0.55mm, extrusion temperature at 280°C, printing speed 40mm/s and lower value of bed temperature 100°C.

TABLE V Analysis of variance (ANOVA) for Build time (min)

Source	DOF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
A	2	17851.6	8925.78	201.21	0.000	67.71 %
B	2	329.6	164.78	3.71	0.047	1.25 %
C	2	1.6	0.78	0.02	0.983	0.006 %
D	2	605.6	302.78	6.83	0.007	2.29 %
E	2	6866.0	3433.00	77.39	0.000	26.04 %
Error	16	709.8	44.36			
Total	26	26364.0				

C. ANOVA for Flatness (F)

Following figure 6. shows of main effects plot for S/N ratio for flatness error with lower the better quality characteristics. This graphs shows optimum combination of FDM parameters for minimum flatness error with layer thickness at 0.2mm, raster width at 0.55mm, extrusion temperature 270°C, bed temperature 100°C and printing speed at 40mm/s. Also table 7 shows layer thickness, raster width, printing speed parameters were the most significant with 74.55%, 5.53% and 12.87% contribution respectively to increase flatness of overhang structure. And table 6 shows importance of parameters by rank 1st, 2nd and 3rd to layer thickness, raster width and printing speed respectively to maintain flatness of overhang structure.

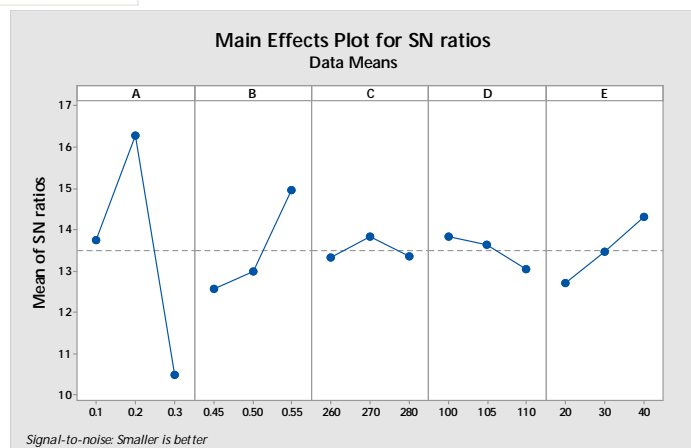


TABLE VI Analysis of variance (ANOVA) for Flatness (mm)

Level	A	B	C	D	E
1	13.72	12.55	13.32	13.82	12.72
2	16.32	12.95	13.84	13.68	13.47
3	10.47	15.01	13.35	13.01	14.32
Delta	5.85	2.46	0.52	0.81	1.61
Rank	1	2	5	4	3

Fig. 6 Main effect plot for S/N ratio of Flatness (mm)

TABLE VII Analysis of variance for Flatness error

Source	DOF	Adj SS	Adj MS	F-Value	P-Value	% Contribution
A	2	0.097520	0.048760	123.52	0.000	74.55 %
B	2	0.016840	0.008420	21.33	0.000	12.87 %
C	2	0.000914	0.000457	1.16	0.339	0.69 %
D	2	0.001979	0.000989	2.51	0.113	1.51 %
E	2	0.007237	0.003619	9.17	0.002	5.53 %
Error	16	0.006316	0.000395			
Total	26	0.130805				

Part printed with 0.1 mm layer thickness were failed to print some initial layers where support structure was not present so this effected on separation of raster in initial layers and this caused to increase flatness error and surface roughness of top surface. But side face roughness values were less than 0.2mm and 0.3mm layer thickness. Following table 8 shows optimal combination of FDM parameters for Ra, BT and F from figure 4, figure 5 and figure 6.

ABLE VIII Optimum parametric combinations for PC-ABS blend material

Performance Measures	Required Quality Characteristics	Input parameters				
		A (mm)	B (mm)	C (°C)	D (°C)	E (mm/s)
Surface roughness (μm)	Lower-the-better	0.1	0.45	270	100	20
Build time (min)	Lower-the-better	0.3	0.55	280	100	40
Flatness error (mm)	Lower-the-better	0.2	0.55	270	100	40

V. CONCLUSIONS

In this research, optimization were done on FDM machine to improve dimensional accuracy of PC/ABS material parts using Taguchi's and ANOVA methods. For that, part printed without support structure to study how to maintain top surface flatness where support structure were not present by proper settings of parameters with lower surface roughness and build time of parts. From above experimentation results following conclusions are obtained

- A. The minimum surface roughness value $5.3994\mu\text{m}$ was obtained with combination of lower values of layer thickness (0.1mm), raster width (0.45mm), bed temperature (100°C), printing speed (20mm/s) and medium level of extrusion temperature (270°C). ANOVA results from table 3. and S/N ratio graph from fig. 4 shows that increase in layer thickness from 0.1mm to 0.3mm, raster width 0.45mm to 0.55mm and printing speed from 20mm/s to 40mm/s were the most significantly effects on to increase surface roughness values with 92.73% and 3.53% respectively contribution in surface roughness.
- B. In the case of flatness error of overhang structure, fig. 6 shows minimum flatness error 0.1052mm was obtained for combination of layer thickness at 0.2mm, raster width at 0.55mm, extrusion temperature at 270°C , bed temperature at 100°C and printing speed at 40mm/s. In this it is observed that initial layers of part printed with 0.1mm layer thickness failed to print initial layers so this effected on to increase flatness error as well as roughness values. ANOVA table 7 of flatness error shows layer thickness, raster width and printing speed were the most significant parameters for maintain flatness with contribution of 74.55%, 12.87% and 5.53% respectively.
- C. Optimum combination for build time was obtained from figure 5 and table 4 at higher values of layer thickness 0.3mm, raster width 0.5mm, printing speed 40mm/s, extrusion temperature 280°C and lower value of bed temperature 100°C . And ANOVA table 5 for build time shows that layer thickness, raster width, printing speed and bed temperature were the most significant parameters to reduce build time of the parts.
- D. But part printed with optimal combination for build time shows worst results in case of surface roughness values so it shows that there is need to use multi-objective optimization which gives optimal combination for multi-pal responses.
- E. In last confirmation of optimal combination of FDM parameters for different quality characteristics were also performed for validation of results and results shows reduction in surface roughness value with $5.2161\mu\text{m}$ and flatness error value 0.0809mm. Also part printed in this study saved material and build time for support structure.

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